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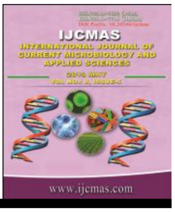

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Higher Leaf Area Improves the Productivity of Finger Millet (*Eleusine coracana* (L.) Gaertn) under Rainfed Conditions

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In the recent past, the grain yield of finger millet has reached a plateau, to break this barrier, multidisciplinary approach more precisely the physiological traits associated with biomass and grain yield would be highly relevant and hence, the present field experiment was conducted. Amongst the two relevant physiological traits (LAI and Net assimilation rate), the relationship of LAI with biomass and grain yield was positive and significant, while DM/LAD (Net assimilation rate) was not significant. The contribution of LAI and DM/LAD towards biomass at flowering was 69.3 and 30.7 percent while at harvest it was 65.2 and 34.8 percent respectively. Accessions possessing high LAI with moderate to high DM/LAD resulted in higher grain yield and such accessions are GE-1034, GE-4222, GE-1013, GE-619 and GE-4248. These accessions may be utilized in crop improvement programmes to break the yield plateau.

Introduction

Finger millet is an important staple food crop of southern Karnataka predominantly grown under dry land conditions in light soils with low input, traditionally in cereal based farming systems during monsoon season. Significant yield improvement was achieved over the years, through exploitation of genetic variability for specific traits, such as blast resistance in addition to agronomic manipulations. Presently finger millet occupies an area of 1.2 mha with a production of 2.0 mt in India (Malhotra, 2018). However there is a decreasing trend in area but with an increased productivity (Anon, 2011) and stagnated grain yield (Swetha, 2011), to break this barrier, an approach of physiological traits associated with grain yield would be highly relevant. Breeding efforts have shown yield improvement of rice and wheat through improved HI, while, in maize through biomass (Richards, 2000). Hence, to break the yield plateau in finger millet, identification of accessions for traits associated with high biomass and its efficient partitioning and;

incorporation of such traits in breeding programmes would be highly effective (Shankar *et al.*, 1990). The present investigation examines the relevance of LAI and net assimilation rate (DM/LAD) towards biomass production and grain yield besides identifying superior finger millet accessions for these traits.

Materials and Methods

Field experiment was conducted during *kharif* season of 2007 at GKVK Farm on red sandy loam soil with a pH of 6.5. Twenty three accessions and ten varieties were replicated twice in RCBD with a net plot size of 1.44 m^2. Crop was managed as per the recommended package of practices (FYM, 7.5 $t.ha^{-1}$ and NPK @ 50:40:25 $kg.ha^{-1}$). Rainfall during the cropping season was 806 mm, but experienced a long dry spell of 27 days during September 21st to October 18th 2007.

Leaf area and biomass at flowering and; yield attributes at harvest were recorded. The total dry matter/ leaf area duration up to flowering (DM/LAD), as a measure of assimilation rate was computed and expressed as g $m^{-2}day^{-1}$. Extent of contribution of LAI and DM/LAD towards dry matter production was computed using standard partial regression co-efficient arrived through multiple regression analysis. The data was analyzed using MSTAT-C programme and correlations among the parameters were computed.

Results and Discussion

Wide genotypic variability was observed for yield, yield attributes and physiological traits viz., LAI, assimilation rate (DM/LAD), biomass etc. (Table 1). A similar large variation for these parameters among 400 finger millet germplasm lines was reported by Shankar *et al.*, (1990) and in another study by Aparna and Ansari (2017) wherein maximum LAI accumulation was observed at 45 DAS. These variations provide an opportunity for selection of trait specific accessions associated with high grain yield (Table 2).

Under adequate input conditions, the crop productivity will be determined primarily by the average canopy cover (LAI), net assimilation rate (DM/LAD) and the crop duration. In the present study, grain yield of mid-duration genotypes was distinctly high (321.9 gm^{-2}) compared long duration (245.4 g) or short (253.4 g) accessions (Table 1) and; the relationship between duration and grain yield is also not positive (r= -0.21, Table 4). These results are in contrast to the expected direct relationship between duration and grain yield (Bedis *et al.*, 2006), because, the long duration genotypes were caught up with dry spell for 27 days during critical stages viz., flag leaf, ear emergence and 50 % flowering. During these critical stages, the long duration accession received only 60.1 mm with 5 rainy days compared to 143.9 mm with 10 rainy days for medium duration accessions (Table 3). Further, long duration accessions coincided with higher soil temperature of 27.3 to 30.2^{0}C at 10cm depth compared to 26.2 to 27.9^{0}C for medium duration types. Hence, the medium duration varieties are better options in the changing climate scenario with more number or long duration of intermittent moisture stress situations during kharif seasons.

Correlation analysis (Table 4) among various physiological and yield attributing traits is very pertinent to establish selection criteria for yield improvement. In physiological terms grain yield is the product of above ground biomass and partitioning of biomass to ear (HI). Among these two, the biomass was strongly correlated to grain yield (r=0.87**) as compared to the HI (r=0.52**) (Table 4). The multiple regression analysis also showed that the contribution of biomass towards grain yield was more (59 %) compared to the HI (41 %). Further, the biomass at harvest and; grain yield are also positively related to yield components viz., ear number (r=0.32, 0.30), ear weight (r=0.90**, 0.95**) and test weight (r=0.45**, 0.69**). Similar correlations in finger millet have been reported by Udayakumar *et al.*, (1986), Sharathbabu *et al.*, (2008), Nandini *et al.*, (2010) and Wolie and Dessalegn (2011).

The HI showed positive relationship with ear weight (r=0.38*), threshing percent (r=0.63**) and test weight (r=0.66**) and not related to LAI (r= -0.06). This indicates that the increase in these yield attributing traits would result in higher grain yield through significant increase in HI. However increase in HI alone may reduce the biomass investment in leaves and other vegetative structures, loosing total biomass production as evidenced in Cv. GPU-67 (Swetha, 2011). Therefore it is appropriate to focus on ways and means to increase the biomass by maintaining at higher HI values in finger millet.

The biomass accumulation is determined by both current photosynthates and remobilization of carbohydrates of the stem to ear during reproductive phase. The current photosynthates in turn depend on functional leaf area (LAD), while the remobilization depends upon the biomass available at the time of flowering when the sink is not a limitation. The biomass production by flowering stage in turn depends on light interception which can be manipulated by the LAI, LAD and leaf angle. However, in finger millet the LAI (2.5) is still low (Uma 1987), but has positive and significant correlation with grain yield and biomass (r= 0.32, 0.41**, Table 4, Kumar *et al.*, 2006 and Sharathbabu *et al.*, 2008). Hence, it appears that LAI is most limiting factor for productivity when net assimilation rate is not a limitation. Further, the leaf area especially with broad leaf is highly inheritable (Richards *et al.*, 2001) and can also be manipulated easily through agronomic approaches such as plant population (Roy *et al.*, 2002), growth regulators (Sujatha and Rao, 2003), nutrition (Khalak and Kumaraswamy, 1994) and weed management (Kumara *et al.*, 2007). Therefore selection of high LAI would result in increased biomass and grain yield of finger millet to break the yield plateau.

The other component of biomass determination, DM/LAD, a measure of net assimilation rate, is poorly related (r=0.20 NS, Table 4), probably finger millet being a C_4 NAD-ME species (Siebke *et al.*, 2003) maintain relatively higher photosynthetic rate and has better photosynthates translocation due to dense minor longitudinal veins (Ueno *et al.*, 2006). These results although suggest that, assimilation rate may not constrain the productivity in finger millet, the short duration accessions possess distinctly higher DM/LAD with lower LAI values, hence, these two traits may compensate each other, thus possibilities of breeding for higher NAR cannot be precluded.

Hence of the two parameters, the contribution of LAI towards biomass production is relatively high compared to net assimilation rate / photosynthetic rate as also reported by Vishwanath (2005) and Subrahmanyam (2000).

Further, the LAI was reported to have positive relationship with seed yield (Veeraputhiran *et al.*, 2009; John and Kumar, 2018), but not the single plant leaf area or flag leaf area (Narayan *et al.*, 2018). In the present study also the contribution of LAI towards biomass production at flowering and crop maturity is 69.3 and 65.2 % respectively compared to DM/LAD of 30.7 and 34.8 percent respectively.

Table.1 Physiological parameters at flowering and yield attributes at harvest in finger millet accessions

Sl. No.	**Accession**	**DFF**	**Grain yield (g. m^{-2})**	**TDM at harvest (g. m^{-2})**	**HI**	**EHW (g. m^{-2})**	**Threshing (%)**	**Prod. Tillers (No. m^{-2})**	**EarNo. ((No. m^{-2})**	**Mean EHW (g)**	**1000 seed wt. (g)**	**LAI**	**LAD (days)**	**TDM at flow. (g m^{-2})**	**DM/LAD (g m^{-2} day^{-1})**	**SLW (mg cm^{-2})**
1	GPU-48	68	245.9	551.9	0.45	300.0	0.82	51.1	55.6	5.39	2.53	1.82	61.7	411.8	6.67	**5.96**
2	Indaf-9	62	364.9	895.3	0.41	466.3	0.80	58.4	70.2	6.60	2.83	1.90	58.9	479.0	8.28	**5.93**
3	VR-708	54	216.0	434.0	0.50	260.4	0.83	74.3	103.5	2.52	3.06	1.32	35.5	264.2	7.43	**6.36**
4	GE-162	58	240.7	607.8	0.40	324.3	0.74	90.0	89.3	3.65	2.10	3.04	88.2	555.1	6.33	**5.61**
5	GE- 1034	63	277.8	622.0	0.44	333.7	0.83	48.3	52.8	6.24	2.86	2.78	87.4	592.4	6.79	**5.18**
6	GE-2770	70	160.1	470.7	0.34	225.7	0.71	86.5	90.7	2.50	1.43	1.44	50.2	249.9	5.07	**5.27**
7	GE-3370	59	220.8	497.8	0.45	267.4	0.83	65.3	118.1	2.29	2.56	2.45	72.3	414.6	5.86	**5.28**
8	GE-4222	63	325.3	719.1	0.45	378.5	0.86	90.7	113.6	3.30	3.02	2.17	68.4	408.4	6.10	**5.55**
9	GE-4732	63	228.8	590.4	0.38	277.8	0.83	43.1	45.9	5.94	2.95	1.45	45.5	319.8	7.06	**6.03**
Mean (SD)		**62**	**253.4**	**598.8**	**0.42**	**314.9**	**0.81**	**67.5**	**82.2**	**4.27**	**2.59**	**2.04**	**63.1**	**410.6**	**6.62**	**5.69**
10	GPU-28	74	328.9	790.6	0.41	495.2	0.67	63.9	108.4	4.59	3.39	2.97	109.9	623.8	5.69	**6.53**
11	Indaf-7	74	275.0	631.2	0.44	356.6	0.78	68.1	93.4	3.86	2.53	1.95	72.2	348.0	4.81	**5.58**
12	HR-911	74	307.7	697.5	0.44	363.9	0.85	61.5	70.5	5.13	2.99	2.00	74.0	331.9	4.49	**5.44**
13	PR-202	73	301.8	637.5	0.47	352.8	0.86	87.9	116.0	3.04	3.13	2.48	90.5	455.4	5.05	**5.34**
14	GE-619	73	339.3	889.4	0.38	426.1	0.80	92.7	201.1	2.13	2.95	3.63	132.3	654.7	4.97	**5.00**
15	GE-1013	74	378.5	832.7	0.46	454.8	0.84	66.0	78.9	5.88	2.68	2.51	92.9	538.7	5.80	**6.30**
Mean (MD)		**74**	**321.9**	**746.5**	**0.43**	**408.2**	**0.80**	**73.4**	**111.4**	**4.11**	**2.95**	**2.59**	**95.3**	**492.1**	**5.14**	**5.70**
16	MR-6	78	365.7	814.5	0.45	446.6	0.83	63.2	72.9	6.09	3.01	3.14	122.5	516.9	4.22	**5.61**
17	Indaf-8	83	269.1	610.9	0.44	343.8	0.79	66.7	67.0	5.17	2.89	2.44	101.1	301.3	2.98	**5.86**
18	L-5	83	247.3	522.0	0.47	306.3	0.81	51.4	59.0	5.24	3.20	1.71	70.8	359.8	5.08	**6.00**
19	GE-224	82	253.8	639.7	0.40	319.8	0.80	95.1	125.7	2.56	2.01	2.35	96.1	370.7	3.89	**5.28**
20	GE-844	82	276.8	657.3	0.41	333.0	0.83	49.0	54.2	6.02	2.37	2.60	106.4	385.7	3.62	**5.23**
21	GE-2858	82	207.3	514.3	0.40	271.6	0.77	61.5	76.1	3.57	2.45	3.21	131.4	530.3	4.04	**5.36**
22	GE-3067	83	233.0	575.9	0.41	301.8	0.77	72.3	77.8	3.89	1.80	2.23	92.3	413.8	4.48	**4.98**

23	GE-3069	82	190.0	584.9	0.33	266.0	0.72	61.9	87.9	3.05	1.39	2.26	92.5	377.0	4.12	**5.41**
24	GE- 3454	82	266.3	665.6	0.40	350.4	0.76	70.5	92.4	3.72	2.40	3.31	135.5	643.3	4.75	**5.81**
25	GE-3457	82	221.9	595.6	0.37	308.0	0.73	86.9	93.1	3.31	2.70	3.56	146.0	516.7	3.54	**5.31**
26	GE-4248	79	362.9	678.4	0.53	425.4	0.86	91.0	124.4	3.37	3.20	2.32	91.4	419.8	4.61	**5.39**
27	GE-4711	82	199.3	534.3	0.37	249.7	0.80	38.6	37.5	6.66	1.97	1.42	58.2	250.9	4.38	**5.84**
28	GE- 4736	83	252.1	673.1	0.38	326.1	0.78	52.8	60.8	5.36	2.59	2.21	91.7	367.9	4.03	**5.65**
29	GE-4738	82	222.6	512.2	0.44	283.4	0.79	52.1	56.6	5.02	1.90	2.86	117.3	508.5	4.34	**5.33**
30	GE- 4777	82	230.2	530.8	0.43	285.4	0.81	50.7	50.7	5.71	2.03	1.80	73.6	312.3	4.27	**5.57**
31	GE-4823	82	216.4	495.5	0.44	295.5	0.73	93.4	105.6	2.81	2.27	2.22	90.8	368.8	4.05	**5.67**
32	GE-4999	94	177.5	569.9	0.31	244.1	0.73	81.6	78.8	3.17	1.69	2.11	98.9	493.7	5.00	**5.08**
33	GE-5192	83	225.4	579.4	0.39	270.2	0.84	45.2	44.1	6.08	2.14	1.89	78.2	359.0	4.59	**5.50**
Mean (LD)		**83**	**245.4**	**597.5**	**0.41**	**312.6**	**0.79**	**65.8**	**75.8**	**4.49**	**2.33**	**2.42**	**99.7**	**416.5**	**4.22**	5.49
Grand Min.			160.1	434.0	0.31	225.7	0.66	38.5	37.5	2.12	1.39	1.31	35.5	249.9	2.98	**4.98**
Grand Max.			378.5	895.2	0.53	495.1	0.86	95.1	201.0	6.66	3.39	3.63	145.8	654.7	8.27	**6.53**
Grand Mean			**261.5**	**624.9**	**0.42**	**330.6**	**0.79**	**67.6**	**84.0**	**4.36**	**2.52**	**2.35**	**88.9**	**428.6**	**5.04**	**5.58**
SEm±			37.5	72.2	0.02	48.7	0.02	7.48	9.2	0.44	0.04	0.20	7.4	27.1	0.32	**0.27**
CD (P< 0.05)			103.9	200.0	0.05	134.9	0.05	20.7	25.4	1.21	0.11	0.55	20.5	75.1	0.89	**0.74**
CV (%)			**20.3**	**16.3**	**6.5**	**20.8**	**2.9**	**15.7**	**15.4**	**14.2**	**2.8**	**12.0**	**11.7**	**9.0**	**9.1**	**6.8**

Table.2 Trait specific accessions/ varieties of finger millet

Trait	GPU-28 (Check)	CD @ 5 %	Better accessions	Significance
Grain yield	328.8 g m^2	103.9	Indaf-9, GE-1013, MR-6, GE-4248	**NS**
Productive tillers	63.9 ($No.m^2$)	20.7	GE-224, GE-4823, GE-619, GE-162, GE-4248, GE-4222	*
No. of earheads	108.4 ($No.m^2$)	25.4	GE-619, GE-224, GE-4248	*
Threshing percent	0.77	0.05	GE-4222, PR-202, GE-4248 (> 86 %)	*
Mean earhead wt.	4.59	1.21	Indaf-9, GE-1034, MR-6, GE-844, GE-4711, GE-5192	*
1000 seed weight	3.39 g	0.11	GPU-28	
Biomass at harvest	790.6 g m^2	200.0	Indaf-9 and GE-619 (> 880 g.m2)	**NS**
Harvest index	0.41	0.05	VR-708, GE-1013, L-5, GE-4248	*
LAI	2.97	0.55	GE-619, GE-3457	*
LAD	110.0 days	20.5	GE-619, GE-3457	*
Biomass at flowering	623.8 g m^2	75.1	GE-619, GE-3454	**NS**
DM/LAD	5.68 g m^2 d^{-1}	0.89	GE-4732, GPU-48, Indaf-9, VR-708, GE-1034	*
SLW	**6.53 (mg cm^2)**	**0.78**	**GPU-28**	

Table.3 Rainfall and soil temperature during crop growth period

Stage of the crop	**Short Duration**	**Medium duration**	**Long duration**
(1) 15 days prior and to Flag leaf stage			
(a) Rainfall (mm)	100 (9)	137.5 (9)	**60.1 (5)**
(b) Soil temperature (0^c) at 10 cm soil depth	23.2	26.2	**27.3**
(2) Flag leaf to Ear head emergence stage			
(a) Rainfall (mm)	86.3 (6)	6.4 (1)	**0**
(b) Soil temperature (0^c) ^{c} at 10 cm soil depth	26.2	27.9	**30.2**
(3) Ear head emergence stage to 50 % flowering			
(a) Days to 50 % flowering	62	74	**83**
(b) Rainfall (mm)	6.4 (1)	0	**0**
(c) Soil temperature (0^c) at 10 cm soil depth	27.8	29.3	**36.1**
(4) 50 % flowering to 50 % grain filling stage			
(a) Rainfall (mm)	0	43.2 (1)	**144.6 (9)**
(b) Soil temperature (0^c) at 10 cm soil depth	**29.1**	**35.3**	**28.9**

Note: (1) Date of sowing, 03-08-2007

(2) No rainfall during 21st September to 18th October, 2007

(3) Values in parenthesis indicates number of rainy days

Table.4 Relationship between physiological, growth and yield attributes in finger millet genotypes

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Parameters	**DFF**	**TDMH**	**HI**	**Straw wt**	**Thr %**	**Ear wt.**	**Ear No.**	**PT No.**	**1000 seed wt.**	**LAI**	**LAD**	**TDMF**	**DM/LAD**	**SLW**
1) Grain yield	-0.21	0.87**	0.52**	0.58**	0.41*	0.95**	0.30	0.12	0.69**	0.32	0.19	0.43*	0.21	**0.23**
2) Biomass at harvest (TDMH)			0.05	0.88**	0.12	0.90**	0.32	0.12	0.45**	0.41*	0.31	0.54**	0.15	**0.11**
3) HI				-0.34*	0.63**	0.38*	0.10	0.04	0.66**	-0.06	-0.16	-0.04	0.19	**0.30**
4) Straw weight					0.09	0.59**	0.23	0.04	0.13	0.32	0.27	0.42*	0.09	**-0.12**
5)Threshing %						0.12	-0.10	-0.22	0.42*	-0.24	-0.32	-0.21	0.22	**-0.03**
6) Ear weight							0.34*	0.16	0.64**	0.41*	0.29	0.53**	0.18	**0.30**
7) Earhead number								0.80**	0.22	0.41*	0.29	0.36*	0.01	**-0.23**
8) Productive tiller number									0.01	0.31	0.24	0.21	-0.10	**-0.30**
9) 1000 seed weight										0.16	0.02	0.23	0.31	**0.43***
10) LAI											0.92**	0.84**	-0.30	**-0.29**
11) LAD												0.71**	-0.57**	**-0.34***
12) Biomass at flowering (TDMF)													0.13	**-0.10**
13) DM/ LAD														**0.41**

* (0.34) and **(0.44) represents significance at 5 % and 1 % respectively

Therefore, an increase in LAI would lead to increased biomass and grain yield especially in medium duration varieties in the changing climate scenario. The accessions GE-1034, GE-4222 (short duration), GE-1013, GE-619 (medium duration) and GE-4248 (long duration) possessing high leaf area with moderate to high assimilation rates would serve as donors in breeding programmes, possibly to break yield plateau of finger millet.

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